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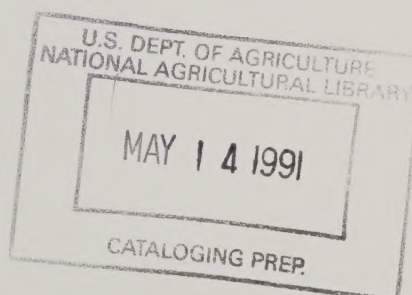
THE BIOLOGICAL AND ECONOMIC ASSESSMENT
OF CADMIUM

A Report of the
USDA-States-EPA
Cadmium RPAR Assessment Team

This report is a joint venture of the U. S. Department of Agriculture, the State Land Grant Universities, and the U. S. Environmental Protection Agency. It was prepared by a team of scientists from these organizations and is an attempt to provide the best science available on the benefits of, and exposure to, cadmium.

The report is not intended to be a policy statement nor a position of advocacy for or against the use of a particular chemical. It is to be used in connection with other data as a portion of the total body of evidence in a final benefit/risk decision under the Rebuttable Presumption Against Registration Process in connection with the Federal Insecticide, Fungicide, and Rodenticide Act.

May 6, 1981



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ABSTRACT

Cadmium fungicides are applied only to turf and comprise less than 0.2% of total U. S. cadmium usage. Approximately 70% of the total cadmium fungicide used is applied to sports turf (largely golf courses); sales direct to homeowners comprise only 15%. The turf diseases controlled by cadmium fungicides consist of dollar spot, copper spot, red thread, and gray snow mold. Cadmium fungicides are inexpensive, effective agents against the latter three diseases but are less effective against dollar spot in some locations because of tolerance to cadmium by the dollar spot fungus.

Although varying in occurrence and severity, all four diseases can cause sufficient economic damage to warrant preventative measures. Because cultural and biological controls are inadequate, fungicide application is the method of choice. Suitable alternatives to cadmium fungicides are available to the homeowner, who would suffer no significant hardship if cadmium fungicides were no longer sold directly to him. Satisfactory alternatives for the professional user are also available, but loss of cadmium would result in not only increased expense but also an earlier appearance or increased buildup of tolerance to the alternative fungicides, which would lose their efficacy. Also, some of the alternatives are more phytotoxic.

A recent study indicates that worker exposure to cadmium is less than previously believed. Because of the protective clothing and mask used by applicators, their dermal or inhalation exposure is minimal. Cadmium binds to soil organic matter and is unlikely to enter into any food chain.

Cadmium fungicides are very economical. Treatment costs show sizable increases if cadmium fungicides are replaced with alternatives. On a worst case basis, the cost increases for gray snow mold prevention would be \$116,300; for red thread, \$180,700; for dollar spot, \$3,000,000; and for copper spot, \$4,900,000. However, the major economic damage could very well be the buildup of tolerance or resistance of disease-causing fungi to the alternative fungicides.

INTRODUCTION

All registrations for the use of cadmium on food crops were cancelled in 1968 (PR notice 68-6 dated February 1968), but formulations of cadmium compounds as sprays, dusts or granules have continued in use as fungicides for the control of some diseases of turf. The EPA Cadmium Working Group has concluded that pesticide products containing cadmium meet or exceed the risk criteria relating to oncogenesis and mutagenesis. Certain uses of cadmium pesticides also meet or exceed the criteria relating to teratogenicity and fetotoxicity. Consequently, a Rebuttable Presumption Against Registration was issued for all pesticides containing cadmium on October 18, 1977 (6).

The RPAR process compares the benefits of a pesticide to the nation and individual users relative to the potential risk resulting from usage. The purpose of this report by the Cadmium Fungicide Assessment Team is to present biological, exposure, and economic information related to cadmium pesticide use under the purview of the U. S. Department of Agriculture. The report provides an overview of cadmium fungicide use in turf management, an appraisal of the benefit/risk situation, and an evaluation of the economic impact if these fungicides are removed from registration.

PROPERTIES OF CADMIUM FUNGICIDES

Physical and Chemical Properties

Cadmium fungicides include cadmium chloride (Caddy, Cadtrete, and Cleary Granular), Cadmium sebacate (Kromad) and cadmium succinate (Cadminate). Cadmium chloride (CdCl_2) is a water soluble inorganic compound with a melting point of 568°C and a boiling point of 960°C . Its density is 4.05. The LD_{50} of cadmium chloride administered orally to rats is 88 mg/kg. Cadmium sebacate ($\text{Cd}(\text{OCO}(\text{CH}_2)_8\text{COO})$) is an organic cadmium compound. When administered orally to rats, its LD_{50} is 400 mg/kg. Cadmium succinate ($\text{Cd}(\text{OCO}(\text{CH}_2)_2\text{COO})$) is an organic cadmium compound with an LD_{50} of 660 mg/kg when administered orally to rats.

Fate in the Environment

How much is known about the reactions of cadmium in soil. Cadmium is retained strongly in organic matter (17, 18). This absorbed form is thought to be a major source of exchangeable cadmium in soil (13). After initial adsorption as an exchangeable ion, sorption or precipitation in insoluble hydroxide or phosphate occurs. The amount of cadmium which can be extracted from soil tends to decrease with time and thus indicates a slow reversion to less soluble forms. Because cadmium is held by the solid surfaces of the soil, it does not readily move down the soil profile (24).

Cadmium is absorbed easily through the roots of many plant species, including Gramineae (15), and may translocate to the leaves (12).

PRODUCTION AND SALES DISTRIBUTION OF CADMIUM FUNGICIDES

In the Cadmium Position Document I the number of Federally registered cadmium formulations is listed as thirty-five, with one State registration with Federal registration pending (6). In 1975, EPA estimated that at least one-half of these were inactive. Cadmium chloride, cadmium sebacate and cadmium succinate remain as the three cadmium compounds currently being formulated.

Cadmium fungicides comprise less than one-fifth of one percent of total cadmium usage in the United States (7). About 12,000 pounds of pesticidal cadmium were produced in 1975. Production for 1976 was reported by the EPA to have exceeded 20,000 pounds, increasing in 1977 to 40,000 pounds (6). The accuracy of the 1976 and 1977 figures has been challenged by representatives from industry who consider that current reporting procedures grossly exaggerate production. Primary producers and formulators both report the same active ingredient, and this duplication is responsible for the inflated production figures. A realistic estimate of the totals for 1976 and 1977, provided by representatives of W. A. Cleary Chemical Corporation and Mallinckrodt, Inc., is approximately (and not greater than) 15,000 pounds. For 1979, industry representatives have provided a figure of 21,397 pounds as a realistic estimate of cadmium fungicide production (21, 22) (Table I).

The two major producers, W. A. Cleary Chemical Corporation and Mallinckrodt, Inc., probably supply in excess of 90% of the cadmium fungicide demand. W. A. Cleary Chemical Corporation, the largest individual producer, markets four products based on cadmium chloride in seventeen states, predominantly in the Eastern United States; New Jersey, New York, Massachusetts, and Pennsylvania absorb the bulk of this commerce. Cadmium chloride is also supplied to several formulators. It is estimated by the two major producers that final sales are in the ratio 70:30 for use on sports turf (mainly golf courses) and home lawns, respectively. A portion of this home lawn usage is by contract lawn care professionals, and the homeowner is not directly involved in fungicide application.

Mallinckrodt, Inc., has a lower sales volume but wider distribution. It markets two products in 28 states: one based on cadmium succinate and one based on cadmium sebacate. Pennsylvania, New York, Ohio, and Illinois are the major consumers. Both of these fungicides are sold almost exclusively to the professional turf manager.

Other producers are involved in the small scale formulation of cadmium chloride and their sales distribution is not known. It can be generalized that cadmium chloride, in liquid, wettable powder or granular formulations, is the commonest cadmium fungicide, followed by cadmium succinate, and finally, cadmium sebacate. The latter two are formulated as wettable powders.

All three cadmium compounds are used by professional turf managers, who constitute the bulk of the cadmium fungicide market. Of the estimated 21,397 pounds active ingredient sold, just over 3,000 pounds, or 15 percent, is sold for home use (Table I). This small market direct to the homeowner is mainly in cadmium chloride products.

Table 1. Cadmium Fungicides: Formulations, Application rates, Pounds Sold and Estimated Treated Acreage 1979

Common Name	Trade Name	Formulation (a.i.) c/	Rate per 1000 sq. ft.		Pounds per acre (a.i.)	Pounds Sold (a.i.)	Estimated Treated acreage d/
			Formulated Product	Active Ingredient			
-----ounces-----							
Cadmium Chloride <u>a/</u>	Caddy	20.1% - L	1.0	.20	.54	11,409	21,128
	Cadtrete	8.5% - WP	3.0	.25	.68	674	991
	Cadtrete	0.38% - G	128.0	.50	1.36	260	191
	Cleary	0.75% - G	32.0	.24	.65	362	557
	Caddy	20.1% - L	1.0	.20	.54	3,172 <u>e/</u>	5,874
Cadmium <u>b/</u> sebacate	Kromad	5.0% - WP	3.0	.15	.41	2,037	4,968
Cadmium <u>b/</u> succinate	Cadminate	6.0% - WP	0.5	.30	.82	3,483	4,248
Total						21,397	37,957

a/ Sartoretto, Paul, 1980, Technical Director, W. A. Cleary Corporation, Somerset, New Jersey, 08873, personal communications.

b/ Small, W. A., 1980, Manager, Specialty Agricultural Products, Research and Development, Mallinckrodt, Inc., St. Louis, Missouri, 63147, personal communications.

c/ Active ingredient - a.i.; liquid - L; granular - G; and wettable powder - WP.

d/ Pounds sold (a.i.) divided by pounds per acre (a.i.).

e/ Estimated use for home lawns. All others are for golf courses.

BIOLOGICAL INFORMATION

Commodity Information

Turfgrasses are grown throughout the United States for functional as well as ornamental value. In addition to the demand for uniform, attractive turf by homeowners, businessmen, landscape contractors, cemetery and garden managers, etc., high quality turf is a necessity for golf courses and athletic fields.

The acreage of turfgrasses grown in the United States is not known precisely. Smiley (23) estimated that this acreage consisted of 15 million acres, including a golf course turf acreage of 1.0 to 1.25 million acres. Annual maintenance expenditures for golf courses were estimated to comprise 500 to 600 million dollars.

Pest Information

Four diseases are controlled effectively by cadmium compounds. These are:

1. Dollar spot, caused by Sclerotinia homeocarpa.
2. Copper spot, caused by Gloeocercospora sorghi.
3. Red thread, caused by Corticium fuciforme.
4. Gray snow mold, caused by Typhula incarnata and other Typhula species.

Dollar spot: This disease is internationally recognized as a widespread and damaging disease of all types of turf. It is particularly severe on bentgrass putting greens. The causal fungus is a ubiquitous, facultative saprobe (i.e., it is usually a parasite but can subsist on dead plant material for food). S. homeocarpa is quiescent during the winter but is active from April-May onwards, depending on the location. Typically, turf is killed in small straw-colored spots 1-3" in diameter, but as the number of infection centers increases, the spots coalesce to involve large areas of turf. Dollar spot may cause serious damage to close-mown turf on golf course greens and tees and severely impair the appearance of fairways and rough throughout the growing season. Dollar spot is one of the most common disease problems on turf in the United States.

Copper Spot: This is a disease of sporadic occurrence on bentgrasses in the United States, especially velvet bentgrass. Copper spot is restricted on golf courses to bentgrass greens, particularly velvet bentgrass ones. Resting structures (sclerotia) become active and initiate infection of the turf in July-September and produce symptoms similar to dollar spot, but the spots are copper colored. Outbreaks are limited to midsummer and tend to be very sporadic. Moderate to severe damage to turf may occur under optimum conditions but severe epiphytotics, i.e., widespread and destructive outbreaks, are rare. Thus, this disease has less potential to cause severe damage to golf course turf than the other three turf diseases effectively controlled by cadmium fungicides. Nevertheless, when it does occur, this disease is damaging and warrants preventive measures.

Red thread: This is internationally recognized as a widespread and disfiguring disease of all types of turf. The causal fungus is another ubiquitous, facultative saprobe and is active over a wide range of temperatures. Resting structures (stromata), resting mycelia or saprobic mycelia initiate infection of the grass leaves and subsequently colonize the plant crowns. Bleached or straw-colored patches result; these may coalesce and involve large areas of turf. Crowns of individual plants may survive but recovery is slow. Severe damage may result from late season infections, especially on perennial ryegrass. Red thread affects areas on golf courses similar to those affected by dollar spot. Although red thread is less permanently damaging than dollar spot, it is extremely disfiguring and unsightly. It is very common and is most troublesome in the cooler regions of the United States.

Gray snow mold: (Typhula blight, snow scald). This is a low temperature disease common on turf in North America, Northern Europe and Japan and is particularly damaging under deep and prolonged snow cover. Over-summering resting structures (sclerotia) germinate in the fall and initiate infection of the turf prior to snow fall. Activity of the fungus under the snow cover results in disfigurement or death of the turf in variable-sized bleached patches up to two feet in diameter. These patches often coalesce to involve extensive areas of turf. This very common disease, alone or in combination with pink snow mold, may decimate unprotected turf and thus constitutes a major hazard wherever persistent snow cover can be expected. Preventative fungicide treatment is imperative in regions of heavy snowfall to protect greens, tees and, in some instances, fairway turf from snow molds, especially gray snow mold.

Development of Cadmium Fungicides for Turf Use and Present Status

The Agricultural Experiment Station at the University of Rhode Island was largely responsible for the development of cadmium fungicides for use exclusively on turf. Dr. F. L. Howard directed this research and published the successful results of trials with phenylaminocadmium dilactate against copper spot and dollar spot in 1947 (10). By 1951, cadmium-containing fungicides, applied every 14-28 days at a rate of 0.3 oz actual cadmium per 1000 square feet, were established as the most specific and safe agents for the prevention and cure of dollar spot and were the recommended fungicides for control of copper spot and red thread. Their effectiveness against gray snow mold was later confirmed (11).

During the 1950's and early 1960's, cadmium based fungicides served as the mainstay for dollar spot control both in the United States and foreign countries such as Australia and Great Britain. In 1965, instances of the failure of cadmium compounds to provide satisfactory dollar spot control were reported in the eastern regions of the United States. By 1970, tolerance of the dollar spot fungus to cadmium, mercury and anilazine based fungicides was also well documented. Alternatives to cadmium for dollar spot control included the then newly-developed benzimidazole group of systemic fungicides, but, after a period of outstanding success, tolerance to these systemic materials by the highly adaptable dollar spot organism was widely reported (4).

Other turf diseases are listed on some current product labels, including brown patch (Rhizoctonia solani), Pythium blight (Pythium spp.), leaf spot and melting out (Helminthosporium spp.), and fading out (Curvularia spp.). However, in a national survey conducted in 1966, cadmium fungicides were rated as being not very effective against these diseases (9) and are no longer recommended. For this reason, and also because the latter group of diseases are not the primary targets of cadmium fungicides, this report will be limited to an evaluation of cadmium fungicide use for the control of copper spot, dollar spot, red thread, and snow mold.

The present status of cadmium-based fungicides is that of agents which are inexpensive and effective against copper spot, red thread and gray snow mold but are less effective against dollar spot in some localities due to tolerance problems. Current changes in fungicide recommendations, in particular the new policy of alternating fungicides in disease control programs to preclude tolerance selection pressure, presumably will minimize any further spread of dollar spot tolerance and help prolong the efficacy of cadmium (and other) fungicides.

Use of Cadmium Fungicides

1. Use by the Homeowner

Quality of turf to the homeowner is very subjective and acceptable standards differ enormously. Few homeowners are fully conversant with the basics of turf management, and the ability to diagnose correctly any one of a large number of lawn problems is uncommon. Fungal diseases certainly may reduce turf quality, but in already mediocre turf, diseases are of little consequence. Often the correction of management deficiencies and the control of weed and insect pests affords such an improvement that any depredation by fungal diseases can be tolerated. Hence, homeowner turf fungicide use is small. It includes both the occasional use by the uninitiated as a last-resort attempt to solve some undetermined lawn problem as well as the correct use by the few informed "lawn buffs" to control a particular disease. In both situations, one or more curative applications (after the symptoms appeared) would be the rule, rather than repeated preventive applications.

Of the four diseases controlled by cadmium fungicides, red thread, dollar spot and gray snow mold could be encountered in home lawns. Since red thread damage is frequently superficial and the symptoms readily suppressed by improving the fertility level, this disease seldom warrants fungicide treatment by the homeowner. Dollar spot symptoms may be sufficiently severe to warrant treatment but, as with red thread, increase in fertility level will mask the depredations of the fungus sufficiently enough to satisfy the majority of homeowners. Since other diseases (e.g., leaf spot and brown patch) may occur during the same period as or together with dollar spot, an alternative fungicide with a broader spectrum compensates for difficulties in diagnosis and is thus a better choice for homeowners for dollar spot control. Gray snow mold requires preventive treatment in the late fall. One well-timed application of cadmium fungicide protects the turf, and in areas of

expected prolonged snow cover this treatment is advised. As mentioned previously, few homeowners carry out preventive fungicide programs, yet treating snow mold symptoms in the spring is entirely ineffective because the damage has already been done. The number of homeowners which use cadmium fungicides for snow mold control and the number which use them effectively is not known; it is surmised that the number is few. Recently, a number of combination fertilizer/fungicide mixtures have become popular with homeowners. These products generally contain broad spectrum fungicides, are easily applied, are readily available, and are cost efficient in most cases. Thus, they satisfy the needs of the average homeowner. Therefore, the need for cadmium fungicides by the homeowner is difficult to support; the inference is that no hardship would result if they were no longer available to the general public.

2. Use by the Professional Turf Manager

This category includes golf superintendents, parks personnel and grounds-keepers, as well as contract landscapers and lawn maintenance operators, all of whom should have pesticide applicator's licenses. Golf courses undoubtedly absorb the bulk of the cadmium fungicide use.

Much higher standards than those of homeowner managed turf are expected of professionally managed turf. Indeed, high turf quality is a requisite for many sports activities, and the provision of true playing surface, especially in the game of golf, is an exacting science. Prevention of fungal diseases plays an important role in the management program because intensively managed turf is highly vulnerable to infection and, if unprotected, may deteriorate rapidly. Golf superintendents are especially aware of the problems that can occur; disease may ravage greens turf in a matter of hours, and the resulting damage may take weeks or even months to repair. The repercussions are such that customers are deterred, members incensed and the superintendent's job is in serious jeopardy. Consequently, the emphasis by the professional manager is to prevent disease rather than to cure established infections.

Disease prevention involves minimization of risk by manipulation of various cultural measures, such as fertilizer practices, irrigation procedures, topdressing, cutting height, etc. However, even the most skillful manager cannot depend solely on cultural control measures and must resort to regular fungicide use to maintain disease-free turf.

The usual practice is to implement a regular spray schedule throughout the growing season and, where necessary, to apply preventive snow mold fungicides in the late fall. Both granular and spray formulations of fungicides are utilized on golf courses. Dry application needs less capital expenditure and is often more convenient for snow mold treatment, but spraying is generally accepted as the more efficient means of application and is the one most commonly employed. The equipment and procedures described by Smiley (23) for application of PCNB to turf are identical to those used for application of cadmium fungicides. Ground based equipment is used almost exclusively.

The average annual maintenance budget for an eighteen-hole golf course in 1969 was \$65,000, although there was large variation on each side of this figure (1). Of this total, between five and ten percent is expended on pesticides, perhaps half of this pesticide expenditure pays for fungicides. As discussed previously, dollar spot, copper spot, red thread and snow mold can cause severe damage to all grassy areas of a golf course and thus warrant preventive measures. Cadmium fungicides figure prominently in the spray program of many superintendents as proven and effective materials for controlling the four diseases listed previously and particularly dollar spot.

The frequency of application of cadmium fungicides is described in the following section.

Role of Cadmium and Alternative Fungicides in Turfgrass Management

There are no means for turf disease control by biological or cultural methods. In the absence of a universal turf fungicide, turf diseases must be correctly diagnosed and the appropriate fungicide must be applied. Table 2 lists the four diseases in question, current fungicide recommendations, and minimum application rates per thousand square feet (5, 22). Spectrum of activity, effectiveness, frequency of application, phytotoxicity, possible human hazard, and possible environmental hazard need to be considered in order to evaluate the merits of these fungicides.

Spectra of Activity. Table 2 shows the variation in activity spectra. The snow mold listings allow for some confusion since the different fungal causal agents respond differently to particular fungicides. Those designated "x" are effective against pink snow mold; "xx", against gray snow mold; "xxx", both.

Effectiveness. Cadmium fungicides are used for prevention and control of many turf diseases. However, overall effectiveness of cadmium and alternative fungicides is difficult to determine. Factors such as geographical location (soil type), temperature, humidity, extent of the disease infestation and previous control measures used (cultural and/or chemical which may affect disease resistance) play an important role in evaluation of the effectiveness of all turf fungicides. To properly ascertain effectiveness, use should be examined on a regional or a local basis.

Against red thread and copper spot all the listed materials perform satisfactorily as preventive materials when applied routinely at the minimum rate on a seven-to-ten day spray schedule. The dollar spot control picture is now somewhat confused due to the increasing appearance of tolerant biotypes of the fungus to cadmium fungicides and the more recently developed anilazine (Dyrene) and benzimidazole fungicides. The benzimidazole group of systemic materials includes Tersan 1991 (benomyl), Fungo and Spot Kleen (thiophanate methyl), Cleary 3336 (thiophanate ethyl), and Mertect (thiabendazole). Of the remaining products available, thiram, mancozeb, and PCNB are mediocre performers. This leaves cycloheximide, chlorothalonil, and the recently registered iprodione (Chipco 26019) as the three reliable dollar spot fungicides. Whether this adaptable fungus can develop mechanisms to circumvent the action of these compounds is an open question.

Table 2. Turf disease control and application rates of cadmium fungicides and principal alternatives

Fungicide and Formulation	Red	Copper	Dollar	snow	Minimum rate (oz.)	
	thread Control	spot Control	spot Control	mold Control	Formulation	applied per 1000 sq. ft. Active Ingredients
Caddy						
-cadmium chloride * 20.1% L		x	x		1.0	0.20
Cleary granular (Twin Light Granular)						
-0.75% cadmium chloride *						
+ 5.0% thiram		x	x	xx	3.2	1.84
Cadtrete						
-0.38% cadmium chloride *						
+ 2.5% thiram G				xx	128.0	3.69
-8.5% cadmium chloride						
+ 75% thiram WP		x	x	xx	3.0	2.51
Cadminate						
-cadmium succinate * 60% WP	x	x	x	xx	0.5	0.30
Kromad - 5% cadmium sebacate *, 1%						
malachite green + 16% thiram WP	x	x	x		3.0	0.66
Spot Kleen						
-thiophanate methyl * 70% WP		x	x		0.75	0.53
-Fungo 50 - thiophanate methyl * 50% WP	x	x	x	x	1.0	0.50
Cleary 3336 -						
-thiophanate ethyl - 50% WP	x	x	x		1.0	0.50
Mertect-thiabendazole - 60% WP			x	x	1.0	0.60
Tersan 1991 - benomyl * - 50% WP			x	x	2.0	1.00
Tersan SP-chloroneb - 65% WP				xx	6.0	3.90
PCNB * 75% WP			x	xxx	4.0	3.00
Actidione TGF						
-cycloheximide - 2.1% WP			x		1.0	0.021
Actidione RZ						
-1.3% cycloheximide			x		1.2	0.92
+ 75% PCNB * - WP						
Actidione Thiram						
-0.75% cycloheximide					2.0	1.52
+ 75% thiram WP		x	x	x	4.0	2.00
Dyrene - anilazine - 50% WP						
Daconil-chlorothalonil						
-4 F	x	x	x		3.0	1.50
-75% WP	x	x	x		2.0	1.50

Table 2. Turf disease control and application rates of cadmium fungicides and principal alternatives

Fungicide and Formulation	Red	Copper	Dollar	snow	Minimum rate (oz.) applied per 1000 sq. ft.
	thread Control	spot Control	spot Control	mold Control	
	:	:	:	:	Formulation
Fore - mancozeb * - 80% WP	x		x	x	4.0
Thiramad - thiram - 75% WP			x	xxx	2.5
Tersan 75 - thiram - 75% WP			x	xxx	3.0
Spotrete - thiram - 4F			x	xxx	3.0
Captan *		x			
Chipco 26019 - iprodione - 50% WP			x	xxx	0.75
PMAS-phenylmercuric acetate - 10% WP				xxx	2.0
Calo-clor-mercurous/mercuric chloride - 90% WP				xxx	3.0
Calo-Gran-mercurous/mercuric chloride - 2.7% G				xxx	128.0
					3.20
					1.88
					2.25
					1.50
					0.38
					0.20
					2.70
					3.46

★ RPAR issued.

a/ Snow mold control is described as follows: "x" indicates control of pink snow mold (Fusarium nivale), "xx" indicates control of gray snow mold (Typhula sp.), and "xxx" indicates control of both.

It is now realized that the buildup of tolerance is a consequence of the repeated and consistent use of a particular fungicide. Tolerance buildup can be avoided by use of a program in which a good selection of different materials is alternated. Cadmium fungicides had (and still have in some areas) an excellent record against dollar spot. Their inclusion as a component of the spray program should ensure their continued inexpensive use against dollar spot.

Mercurial fungicides, now restricted to the professional user, give excellent protection against the two common snow molds. PCNB and thiram are moderately effective against both, but application of 2-3 times the minimum rate is needed to provide winter-long protection. Cadmium fungicides at 2-3 times the minimum rate and chloroneb at 1-1.5 times the minimum rate are specific for gray snow mold. Mancozeb (2 times minimum) and the systemic benzimidazoles at 3-4 times the minimum rate are specific for pink snow mold. Anilazine, although labelled, is a very poor snow mold fungicide even at 3-4 times minimum rate. Therefore, cadmium fungicides serve as efficient and inexpensive fungicides for the prevention of gray snow mold and may serve as a component of mixed treatments to control all snow molds.

Frequency of Application. Frequency of application varies with the disease to be controlled. Red thread occurs mainly in the cooler spring and fall periods. A preventative spray program of contact fungicides specifically for red thread control may involve three to four applications in the spring and a similar number in the fall. For copper spot, a similar program may involve six to eight applications during July through September 1. Dollar spot may appear a little sooner than copper spot and persist later into the fall; hence eight to ten applications may be required. Many golf course superintendents apply fungicides on a weekly schedule from June through September and thus make twelve to sixteen applications. The systemic fungicides may provide longer protection than contact materials, i.e., for 14 to 21 days. Hence the number of applications may be halved. However, claims for this effect have not always been borne out in practice; 10 to 14 days may be a more realistic interval. The standard practice for snow mold control by fungicides consists of a preventive application in the fall prior to snowfall plus an optional secondary application during the January thaw. Application rates higher than the listed minimums are required.

Phytotoxicity. Phytotoxicity is not a problem with cadmium fungicides, but some of the alternative materials do injure or discolor turf occasionally. If applied in hot weather, cycloheximide and PCNB both may injure bentgrass turf. Chloroneb and mercurous/mercuric chloride fungicides applied for snow mold may discolor turf and slow spring greenup.

Exposure

There are no means of controlling turf diseases by cultural or biological control methods, hence chemical controls are needed. Professional turf managers understandably view with alarm the possibility of any further withdrawals from the already dwindling list of turf fungicides. Spraying of cadmium fungicides is the most common means of application, but a certain amount is used in the granular formulation and applied by drop or cyclone

spreader. In "Preliminary Analysis of Human Exposure to Cadmium from the Use of Cadmium Turf Fungicides" (8), a dermal exposure from a typical cadmium spray formulation was estimated at 0.08g, 1.6mg of this being absorbed via the skin. Inhalation exposure was estimated in the region of "two orders of magnitude less than dermal exposure." The dermal exposure calculation was based on the assumption that one pint of diluted spray liquid was collected by the operator's clothes.

Results of a practical evaluation (22) involving the treatment with a hand gun of seventeen greens averaging more than 5400 square feet in size with approximately 200 gallons of Cadminate (8 greens) and Kromad (7 greens) indicated that the total amount of solution on the outer garments is closer to one ounce rather than one pint. The actual amount of cadmium on the garments amounted to 2.8mg. Air sampling showed cadmium values to be thirty times lower than those acceptable according to OSHA standards (22). If consideration is given to the required standard practice of wearing impermeable protective clothing and face mask with filter while spraying or spreading pesticides on the golf course, then the risk of dermal or inhalation exposure is further reduced. Cadmium compounds are not volatile and spraying is carried out when no play is occurring.

Sanderstead et al. (19) suggested: "Cadmium is toxic to man and other living things in virtually all of its chemical forms. Threshold doses for long term toxic effects of Cd are not known with certainty, however, Cd tends to accumulate in the body." This accumulation of cadmium by mammals and the ability of cadmium to replace zinc in certain enzyme systems and hence cause disease is the reason for current concern.

Cadmium is present in the earth's crust at an average concentration of 0.18 ppm and is also a ubiquitous contaminant of air, water and soil. Emissions from industrial activities and trash burning and dust from tread wear of car tires all contribute to the aerial load of cadmium. Cadmium concentration in the main stream and lakes draining sixteen major United States watersheds averaged 9.5 µg/litre over the period 1962-67 (15).

The average concentration of cadmium in soils is about 0.06 ppm but levels may be as high as 1.0 ppm in locally polluted areas (3, 18) or calcareous soils (20). The concentration of cadmium decreases with with depth through the soil profile and with increasing distance from local point sources, such as areas with heavy traffic (14, 15). Drainage, microbial activity and pH play a major role in determining local cadmium concentrations in soils (16).

Soils under turf, therefore, have an indigenous cadmium content supplemented by cadmium aerosols deposited directly or in precipitation plus that introduced in the irrigation water. In addition, phosphate-containing fertilizers (15) and processed sewage sludge used on turf may contain appreciable amounts of cadmium (2). Finally, turf fungicide application contributes to the total cadmium presence. The amount of cadmium in the upper profile (top 4 inches) has been

measured in soils from golf courses where cadmium had been applied. These soils had cadmium contents ranging from none detected to 62.5 ppm; the mean was 8.4 ppm (6).

Cadmium is absorbed easily through the roots of many plants species including Gramineae (15) and may translocate to the leaves (12). This cadmium would not enter any food chain unless grass clippings were fed to animals or grazing animals had access to treated turf. Label modification could prohibit grazing domestic animals on cadmium treated turf and feeding grass clippings to domestic animals.

Of more concern is the possibility that cadmium applied to golf course turf may move laterally and contaminate water sources. Half of the sediments collected from ponds and streams near cadmium treated turf have been reported to contain cadmium in amounts up to 94.4 ppm, with a mean of 1.5 ppm (6). This finding needs further validation, since it appears to conflict with reports that cadmium binds readily to soil organic matter. Direct contamination by spray drift or washing of soil particulate matter could account for this lateral movement.

ECONOMIC IMPACT OF LOSS OF CADMIUM FUNGICIDES

Treatment Costs

Cadmium is used in various parts of the country to control the four fungal diseases discussed earlier. Accordingly, these diseases are presented in conjunction with recommended application rates and cost figures for cadmium (Table 3) and effective alternatives (Table 4). The cost figures presented are the average retail costs of the formulated products in 1980 prices throughout the United States. Both the number of applications and quantities of fungicide applied per treatment reflect average disease conditions on infected turf. Fluctuations on either side of the amounts presented do occur. Cost figures for 1,000 sq. ft. areas show individual treatment costs as well as expected annual disease prevention estimates. These estimates are not representative of those which might be found under a rotational spray program but result from a standard procedure with use of one fungicide throughout the season.

Cost Analysis of Loss of Cadmium Fungicides

The following economic evaluation of restricting cadmium use for turfgrass disease control focuses on a cost analysis comparing cadmium with recommended alternative fungicides. Using cost data, a comparison of turf treatments per 1,000 square feet was developed. These cost comparisons were stratified according to disease type, and estimates were developed for cadmium and the alternatives (Table 5). A limitation of these cost figures is that they represent averages for each disease group. Under copper spot there are four cadmium fungicides listed (Table 3) as principle control agents and three alternative fungicides (Table 4). An "expected" seasonal application program is specified for each disease and used for the cost analysis. Included is a range of high and low prices for different fungicides (classified by disease group) to provide a more realistic evaluation of these average price figures.

For each of the diseases, treatment costs show sizable increases when replacing cadmium based fungicides with alternatives (Table 5). Red thread and gray snow mold have the smallest cost increases; copper spot and dollar spot have the largest increases. With use of alternatives, average price changes per 1,000 square feet are \$.45 for red thread (+ 11%), \$.51 for gray snow mold (+ 17%), \$2.26 for dollar spot (+ 26%) and the largest cost increase of \$3.69 for copper spot (+ 50%).

In order to expand the analysis to a national basis, precise turf acreage figures are needed. These are not available. However, use of cadmium sales figures and pounds active ingredient per acre provided an estimate that 37,957 acres were treated (Table 1). It is not known what proportion of these acres are infected with specific diseases or a combination of diseases. Therefore, a series of impacts were developed based on certain assumptions concerning the acreage infected with each disease. Specific cadmium formulations are recommended for each disease, and only those formulations were used in projecting acreages (Table 2). It was assumed that only one disease at a time infects a given turf acreage. For example, under red thread (Table 3) there are two cadmium formulations listed: Cadminate and Kromad. Based on the application rate per 1,000 square feet (Table 2) and the quantity sold (Table

1) it was estimated that, for red thread control, Cadminate (6.0% WP) was used on 4,248 acres and Kromad (5% WP) on 4,968 acres (Table 1). A similiar procedure was used for estimating acreage treated for the other three diseases. It was noted that Cadminate is recommended for all four diseases (Table 3). Therefore, the same quantity sold was used in estimating the acreage treated for each disease. Because of this multiple counting, the acres treated and dollar impact developed in Table 6 cannot be summed. The data presented indicate what the impact would be only if all of a particular formulation sold were used to control a specific disease.

On a national scale, the potential impact of cancellation of cadmium fungicide registration is smallest for gray snow mold disease (GSM) (Table 6). If all acreage treated with Cadminate and Cadtrete were infested with GSM, the dollar impact of cancellation would be \$116,300. After GSM, the next largest impact would result from a single infestation of red thread, with a total cost increase of \$180,700. Total infestations of either copper spot or dollar spot would result in significantly greater economic impact than the other two diseases. The reason for this is that both diseases are treated with Caddy (20.1% L), which accounts for over 60% of total cadmium fungicide sales. These diseases thus have the greatest projected treated acreage. Furthermore, these diseases require more seasonal applications to obtain adequate prevention and control levels (Table 3). The combination of these two factors results in significant cost increases, specifically \$3.0 million for dollar spot and \$4.9 million for copper spot.

Table 3. Cadmium fungicides: diseases controlled, application per season, application rate and cost per 1,000 sq. ft., 1980

Disease	Trade Name	Applications per season			Formulated Product			Cost per 1,000 sq. ft.		
		No.	Range	Expected	Rate per 1000 sq. ft. a/	Cost per pound b/	Treatment	Annual		
									No.	ounces
Red Thread	Cadminate Kromad	2-8	5	0.5	17.40	0.54	2.70			
		2-8	5	3.0	4.65	0.87	4.35			
Copper spot	Cadminate Cleary c/ Caddy Kromad	3-12	7	0.5	17.40	0.54	3.78			
		3-12	7	32.0	1.12	2.24	15.68			
		3-12	7	1.0	2.80	0.18	1.26			
		3-12	7	3.0	4.65	0.87	6.09			
Dollar spot	Cadminate Cleary c/ Caddy Kromad	8-16	12	0.5	17.40	0.54	6.48			
		8-16	12	32.0	1.12	2.24	26.88			
		8-16	12	1.0	2.80	0.18	2.16			
		8-16	12	3.0	4.65	0.87	10.44			
Gray snow mold	Cadminate Cleary c/ Cadtrete-WP	1-3	2	0.5	17.40	0.54	1.08			
		1-3	2	32.0	1.12	2.24	4.48			
		1-3	2	3.0	4.89	0.92	1.84			

a/ Table 1.

b/ Sartoretto, Paul, 1980, Technical Director, W. A. Cleary Corporation, Somerset, New Jersey, 08873, personal communications.

c/ Cleary granular has minimal use: 1.7% of total cadmium fungicides sold. Essentially use is restricted to small golf course operators who lack the equipment to apply liquids or wettable powders.

Table 4. Alternative fungicides to cadmium for control of red thread ason, application rate and cost per 1,000 sq. ft., 1980

Disease	Trade Name <u>a/</u>	Applications per season		Formulated Product		Cost per 1,000 sq. ft.	
		Range	Expected	Rate per 1000 : sq. ft. <u>a/</u>	Cost per : pound <u>b/</u>	Each : Treatment	Annual : :
-----ounces----- Dollars-----							
Red Thread	*Fore	2-8	5	4.0	2.92	0.73	3.65
	*Fungo 50	2-8	5	1.0	11.72	0.73	3.65
	Daconil	2-8	5	2.0	8.00	1.00	5.00
	Cleary 3336	2-8	5	1.0	11.50	0.72	3.60
Copper Spot	*Spotkleen	6-8	7	0.75	16.50	0.77	5.39
	Daconil	6-8	7	2.0	8.00	1.00	7.00
	Dyrene	6-8	7	4.0	5.59	1.40	9.80
Dollar spot	Daconil	8-16	12	2.0	8.00	1.00	12.00
	Actidione TGF	8-16	12	1.0	8.93	0.56	6.72
	*Actidione RZ	8-16	12	1.2	6.52	0.49	5.88
	Actidione thiram	8-16	12	2.0	6.70	0.84	10.08
	Chipco 26019	8-16	12	0.75	14.83	0.70	8.40
Gray snow mold	Calo-clor	1-2	2	3.0	21.00	3.94	7.88
	PMAS	1-2	2	1.0	4.48	0.28	0.56
	*PCNB	1-2	2	4.0	2.08	0.52	1.04
	Tersan 75	1-2	2	3.0	2.72	0.51	1.02
	Tersan SP	1-2	2	6.0	8.00	3.00	6.00
	Chipco 26019	1-2	2	0.75	14.83	0.70	1.40

* RPAR issued.

a/ Table 2.

b/ Sartoretto, Paul, 1980, Technical Director, W. A. Cleary Corporation, Somerset, New Jersey, 08873, personal communications.

Table 5. Changes in turf treatment costs resulting from the substitution of alternative fungicides for cadmium based fungicides. c/

Disease	Average annual costs			Change in Cost			Range in annual Costs		
	Cadmium <u>a/</u>	Alternatives <u>b/</u>	:	Actual	Percent	:	Cadmium <u>a/</u>	Alternatives <u>b/</u>	:
	-----Dollars/1,000 sq. ft.-----			-----Dollars/1,000 sq. ft.-----			-----Dollars/1,000 sq. ft.-----		
Red Thread	3.53	3.98		(+) 0.45	(+) 11		2.70 - 4.35	3.60 - 5.00	
Copper spot	3.71	7.40		(+) 3.69	(+) 50		1.26 - 6.09	5.39 - 9.80	
Dollar spot	6.36	8.62		(+) 2.26	(+) 26		2.16 - 10.44	5.88 - 12.00	
Gray snow mold	2.47	2.98		(+) 0.51	(+) 17		1.08 - 4.48	0.56 - 7.88	

a/ Derived from Table 3.

b/ Derived from Table 4.

c/ Cleary granular is excluded from the average costs due to its minimal use and its high cost per application which would greatly distort the mean annual treatment costs.

Table 6. Projected impact from a cadmium restriction on turf. a/

Disease	Fungicides b/	Change in Cost			Acres treated e/	Cost Increase	Total impact f/
		1,000 sq. ft. c/	Per acre d/				
		Dollars			1,000 dollars		
Red thread	Cadminate Kromad	0.45	19.60		4,248	83.3	180.7
		0.45	19.60		4,968	97.4	
Copper spot	Cadminate Caddy Kromad	3.69	160.74		4,248	682.8	4,877.5
		3.69	160.74		21,128	3,396.1	
		3.69	160.74		4,968	798.6	
Dollar spot	Cadminate Caddy Kromad	2.26	98.45		4,248	418.2	2,987.4
		2.26	98.45		21,128	2,080.1	
		2.26	98.45		4,968	489.1	
Gray snow mold	Cadminate Cadtrete	0.51	22.21		4,248	94.3	116.3
		0.51	22.21		991	22.0	

a/ Cleary granular is excluded from the average costs due to its minimal use and high cost per application, which would greatly distort the mean annual treatment costs.

b/ Table 3.

c/ Table 5, column 3.

d/ Based on 43,560 sq. ft. per acre.

e/ Table 1.

f/ This column cannot be summed because to do so would result in multiple counting of treated acreage.

SUMMARY AND CONCLUSIONS

Cadmium fungicides have proved to be effective and economical in their thirty years of use on turf with no documented ill effects to the user or the environment. Of late, this effectiveness has decreased in some locations because of the development of cadmium-tolerant biotypes of the dollar spot fungus. However, tolerance to some of the alternative fungicides is now evident and thus has prompted a reappraisal of fungicide programs for dollar spot control. The present concept is to alternate a wide variety of fungicides in the control program to obviate tolerance buildup against any one fungicide. Cadmium fungicides, therefore, can still play an important role against dollar spot and continue as effective agents against copper spot, red thread and gray snow mold. With some of the alternative fungicides subject to RPAR review and possible cancellation, it seems doubly important that use of cadmium be retained.

Cadmium compounds do pose a health hazard to man and animals. In applications of cadmium fungicides to turf there is a risk of dermal contact and/or inhalation of spray or dust. By adoption of established safety procedures during application, these risks can be eliminated. The professional user by law must be a licensed applicator who is familiar with these procedures and consequently has the necessary equipment and expertise. The homeowner may not be as well informed or well equipped; this situation warrants justifiable concern. Since the use of the fungicides by the homeowner is small and often ineffectual, the limiting of cadmium fungicide use to the professional turf manager seems to be a logical solution.

Once applied to turf, cadmium compounds add to levels already present naturally and/or that present from various sources of contamination. Cadmium compounds are non-volatile, bind readily to soils and are slow to leach down the soil profile. In turf use, cadmium absorbed by plants should not enter any food chain other than by negligence. Lateral translocation of applied cadmium compounds to adjacent bodies of water remains as one possible hazard which requires further confirmation.

If cadmium fungicides are lost, then the "worst case" cost increase to golf course managers would occur during a total infestation of copper spot with a resulting impact of nearly \$4.9 million. Because there are thousands of golf courses dispersed throughout the country, a treatment cost increase of this size is relatively insignificant. Ultimately, however, this is not the issue. As with any fungicide, the effectiveness and value of cadmium depends on numerous variables (e.g., geographic area, temperature, degree of infestation, humidity, previous application methods, etc.) which must be assessed for specific locations. Those areas of the country which obtain the highest benefit from its use will be the most adversely affected by its cancellation, particularly in the case of dollar spot and copper spot, with cost increases of 26% and 50%, respectively.

Perhaps of greatest concern is the loss or potential loss of many fungicides from the arsenal of controls due to EPA cancellation or a tolerance buildup in disease-causing fungi. In the case of the four diseases discussed herein, and in particular for dollar spot, cadmium is regarded as an essential control agent. With some alternative fungicides subject to RPAR review, a restriction of cadmium would accentuate the tolerance problem and make it that much more a factor to be considered.

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